

**TITLE OF THE INVENTION**

CURABLE BASE-RESISTANT FLUOROELASTOMERS

5                   **CROSS-REFERENCE TO RELATED APPLICATIONS**

                  This application is a division of application Serial No.  
10/138,069 filed May 2, 2002.

**FIELD OF THE INVENTION**

10               This invention relates to polyhydroxy curable fluoroelastomers  
                  comprising copolymerized units of 1) ethylene, 2) a perfluoro ether such  
                  as a perfluoro(alkyl vinyl ether) or a perfluoro(alkyl or alkoxy alkenyl ether),  
                  3) tetrafluoroethylene, and 4) a cure site monomer selected from the group  
                  consisting of i) 3,3,3-trifluoropropene-1, ii) trifluoroethylene, iii) 1,2,3,3,3-  
15               pentafluoropropylene, iv) 1,1,3,3,3-pentafluoropropylene, and v) 2,3,3,3-  
                  tetrafluoropropene.

**BACKGROUND OF THE INVENTION**

                  Base resistant specialty fluoroelastomers made from copolymers of  
20               ethylene (E), a perfluoro(alkyl vinyl ether) (PAVE), tetrafluoroethylene  
                  (TFE) and a cure site monomer are known in the art (U.S. Patent No.  
                  4,694,045). In addition to being resistant to attack by strong bases, these  
                  fluoroelastomers have good sealing properties at both low and high  
                  temperatures and exhibit low swell in oil.

25               In order to fully develop physical properties such as tensile  
                  strength, elongation, and compression set, elastomers must be cured, i.e.  
                  crosslinked. In the case of fluoroelastomers, this is generally  
                  accomplished by mixing uncured polymer (i.e. fluoroelastomer gum) with a  
                  polyfunctional curing agent and heating the resultant mixture, thereby  
30               promoting chemical reaction of the curing agent with active sites along the  
                  polymer backbone or side chains. Interchain linkages produced as a  
                  result of these chemical reactions cause formation of a crosslinked  
                  polymer composition having a three-dimensional network structure.

Commonly used curing agents for fluoroelastomers include difunctional nucleophilic reactants, such as polyhydroxy compounds or diamines. Alternatively, peroxidic curing systems containing organic peroxides and  
5 unsaturated coagents, such as polyfunctional isocyanurates, may be employed.

U.S. Patent 4,694,045 discloses several cure site monomers which may be incorporated into E/PAVE/TFE specialty fluoroelastomers. These include brominated or iodinated alpha-olefins, and various halogenated  
10 vinyl ethers. Such fluoroelastomers may be cured with peroxides or tin compounds, but not polyhydroxy curatives. However, in many end use applications, it would be beneficial to be able to cure E/PAVE/TFE fluoroelastomers with polyhydroxy compounds because of the improved mold release properties and superior resistance to compression set (i.e.  
15 lower compression set) that is imparted by this type of crosslinking system.

Thus, it would be particularly desirable to have an improved specialty E/PAVE/TFE fluoroelastomer that is resistant to alkaline fluids and oil swell and which readily crosslinks with polyhydroxy cure systems  
20 to form cured articles having good tensile properties and compression set resistance.

#### **SUMMARY OF THE INVENTION**

It has been surprisingly found that the introduction of a cure site  
25 monomer selected from the group consisting of i) 3,3,3-trifluoropropene-1, ii) trifluoroethylene, iii) 1,2,3,3,3-pentafluoropropylene, iv) 1,1,3,3,3-pentafluoropropylene, and v) 2,3,3,3-tetrafluoropropene into ethylene/perfluoro ether/tetrafluoroethylene copolymers improves the polyhydroxy curing of these specialty fluoroelastomers without significantly  
30 diminishing the resistance of these fluoroelastomers to alkaline fluids or oil and without significantly altering the low and high temperature sealing

capabilities of these fluoroelastomers. The resulting cured fluoroelastomer articles have excellent compression set resistance and tensile properties.

Accordingly, an aspect of the present invention is a specialty  
5 fluoroelastomer comprising copolymerized units of 10 to 40 mole percent ethylene; 20 to 40 mole percent of a perfluoro ether selected from the group consisting of perfluoro(alkyl vinyl ethers), perfluoro(alkyl alkenyl ethers) and perfluoro(alkoxy alkenyl ethers); 32-60 mole percent tetrafluoroethylene; and 0.1 to 15 mole percent of a cure site monomer  
10 selected from the group consisting of i) 3,3,3-trifluoropropene-1, ii) trifluoroethylene, iii) 1,2,3,3,3-pentafluoropropylene, iv) 1,1,3,3,3-pentafluoropropylene, and v) 2,3,3,3-tetrafluoropropene.

Another aspect of this invention is a curable fluoroelastomer composition comprising

15 A) a specialty fluoroelastomer comprising copolymerized units of 10 to 40 mole percent ethylene; 20 to 40 mole percent of a perfluoro ether selected from the group consisting of perfluoro(alkyl vinyl ethers), perfluoro(alkyl alkenyl ethers) and perfluoro(alkoxy alkenyl ethers); 32-60 mole percent tetrafluoroethylene; and 0.1 to 15 mole percent of a cure site  
20 monomer selected from the group consisting of i) 3,3,3-trifluoropropene-1, ii) trifluoroethylene, iii) 1,2,3,3,3-pentafluoropropylene, iv) 1,1,3,3,3-pentafluoropropylene, and v) 2,3,3,3-tetrafluoropropene;

B) 0.1 to 20 parts by weight per 100 parts fluoroelastomer of a polyhydroxy curing agent;

25 C) 1 to 30 parts by weight per 100 parts fluoroelastomer of an acid acceptor; and

D) 0.1 to 20 parts per 100 parts fluoroelastomer of a vulcanization accelerator.

The polyhydroxy curing agent and vulcanization accelerator may be  
30 present as separate components or as the salt of the curing agent and accelerator.

**DETAILED DESCRIPTION OF THE INVENTION**

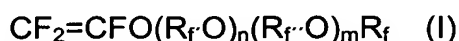
Fluoroelastomers of this invention comprise copolymerized units of  
1) ethylene (E), 2) a perfluoro ether selected from the group consisting of  
5 perfluoro(alkyl vinyl ethers) (PAVE), perfluoro(alkyl alkenyl ethers) and  
perfluoro(alkoxy alkenyl ethers), 3) tetrafluoroethylene (TFE), and 4) a  
cure site monomer selected from the group consisting of i) 3,3,3-  
trifluoropropene-1 (TFP), ii) trifluoroethylene (TrFE), iii) 1,2,3,3,3-  
pentafluoropropylene (1-HPFP), iv) 1,1,3,3,3-pentafluoropropylene (2-  
10 HPFP), and v) 2,3,3,3-tetrafluoropropene.

Minor amounts (i.e. less than about 20 mole percent total) of other  
copolymerizable monomers may also be present in the fluoroelastomers of  
this invention. Examples of such monomers include, but are not limited to  
chlorotrifluoroethylene; vinyl fluoride; propylene; isobutene; and bromine-  
15 or iodine-containing cure site monomers such as  
 $\text{CF}_2=\text{CFOCF}_2\text{CF}_2\text{OCF}_2\text{CF}_2\text{Br}$ ; 1-bromo-2,2-difluoroethylene;  
bromotrifluoroethylene; 4-bromo-3,3,4,4-tetrafluorobutene-1; 4-bromo-  
1,1,2-trifluorobutene-1; 2-bromoperfluoro(ethyl vinyl) ether; 3-  
bromoperfluoro(propyl vinyl) ether; and 4-iodo-3,3,4,4-tetrafluorobutene-1.  
20 Alternatively, bromine or iodine cure sites may optionally be introduced  
onto the fluoroelastomer polymer chain ends by use of iodinated or  
brominated chain transfer agents such as methylene iodide or 1,4-  
diiodoperfluoro-butane during polymerization. The presence of  
brominated or iodinated groups permits the fluoroelastomers of this  
25 invention to be cured by organic peroxides in addition to polyhydroxy  
curatives.

Generally the fluoroelastomers of this invention contain between 10  
to 40 (preferably between 20 to 40) mole percent copolymerized units of  
ethylene, based on the total moles of copolymerized monomers. Less  
30 ethylene adversely effects the low temperature sealing performance of the  
fluoroelastomers, while more ethylene adversely effects the base  
resistance and oil swell resistance properties of the fluoroelastomers.

The fluoroelastomers of this invention typically contain between 20 to 40 (preferably between 20 to 30) mole percent copolymerized units of a perfluoro ether selected from the group consisting of perfluoro(alkyl vinyl  
 5 ethers), perfluoro(alkyl alkenyl ethers) and perfluoro(alkoxy alkenyl ethers), based on the total moles of copolymerized monomers. Less perfluoro ether will negatively impact the low temperature sealing performance of the fluoroelastomers of the invention, while more perfluoro ether causes the polymer to be more expensive to produce.

10 Perfluoro(alkyl vinyl ethers) suitable for use as monomers include those of the formula



where  $\text{R}_f$  and  $\text{R}_f'$  are different linear or branched perfluoroalkylene groups of 2-6 carbon atoms,  $m$  and  $n$  are independently 0-10, and  $\text{R}_f$  is a  
 15 perfluoroalkyl group of 1-6 carbon atoms.

A preferred class of perfluoro(alkyl vinyl ethers) includes compositions of the formula



where  $X$  is  $F$  or  $\text{CF}_3$ ,  $n$  is 0-5, and  $\text{R}_f$  is a perfluoroalkyl group of 1-6  
 20 carbon atoms.

A most preferred class of perfluoro(alkyl vinyl ethers) includes those ethers wherein  $n$  is 0 or 1 and  $\text{R}_f$  contains 1-3 carbon atoms. Examples of such perfluorinated ethers include perfluoro(methyl vinyl ether) (PMVE) and perfluoro(propyl vinyl ether) (PPVE). Other useful  
 25 monomers include compounds of the formula



where  $\text{R}_f$  is a perfluoroalkyl group having 1-6 carbon atoms,  
 $m = 0$  or  $1$ ,  $n = 0-5$ , and  $Z = F$  or  $\text{CF}_3$ .

Preferred members of this class are those in which  $\text{R}_f$  is  $\text{C}_3\text{F}_7$ ,  $m = 0$ , and  
 30  $n = 1$ .

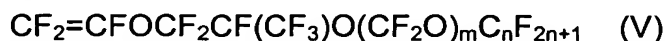
Additional perfluoro(alkyl vinyl ether) monomers include compounds of the formula



5 where  $m$  and  $n$  independently = 0-10,  $p$  = 0-3, and  $x$  = 1-5.

Preferred members of this class include compounds where  $n$  = 0-1,  $m$  = 0-1, and  $x$  = 1.

Additional examples of useful perfluoro(alkyl vinyl ethers) include



10 where  $n$  = 1-5,  $m$  = 1-3, and where, preferably,  $n$  = 1.

Perfluoro(alkyl alkenyl ethers) suitable for use as monomers include those of the formula VI



15 where  $\text{R}_f$  is a perfluorinated linear or branched aliphatic group containing 1-20, preferably 1-10, and most preferably 1-4 carbon atoms and  $n$  is an integer between 1 and 4. Specific examples include, but are not limited to perfluoro(propoxyallyl ether) and perfluoro(propoxybutenyl ether).

20 Perfluoro(alkoxy alkenyl ethers) differ from perfluoro(alkyl alkenyl ethers) in that  $\text{R}_f$  in formula VI contains at least one oxygen atom in the aliphatic chain. A specific example includes, but is not limited to perfluoro(methoxyethoxyallyl ether).

Also contained in the fluoroelastomers of this invention is between 32-60 (preferably 40 to 50) mole percent copolymerized units of 25 tetrafluoroethylene, based on the total moles of copolymerized monomers. Less TFE will adversely effect oil swell resistance whereas higher levels of TFE may introduce crystallinity, thus negatively impacting elastomer properties such as elongation and compression set.

30 The fluoroelastomers of this invention also contain 0.1 to 15 (preferably 2 to 10, most preferably 2-6) mole percent (based on the total moles of copolymerized monomers) of copolymerized units of a cure site monomer. The cure site monomer is selected from the group consisting of

i) 3,3,3-trifluoropropene-1, ii) trifluoroethylene, iii) 1,2,3,3,3-pentafluoropropylene, iv) 1,1,3,3,3-pentafluoropropylene, and v) 2,3,3,3-tetrafluoropropene.

5           It is believed that during the polyhydroxy curing process, some copolymerized units of the cure site monomer, which are located adjacent to tetrafluoroethylene units in the fluoroelastomer polymer chain, dehydrofluorinate to form sites of unsaturation (i.e. C-C double bonds). These unsaturated sites are then available to react with polyhydroxy  
10   curatives to form crosslinks. Fluoroelastomers containing less than 0.1 mole percent units of one of these cure site monomers do not form a sufficient number of crosslinks to yield a cured product having desirable tensile properties for most end uses. Fluoroelastomers containing more than 15 mole percent of these cure site monomers are not desirable  
15   because i) the polymerization rate is reduced and ii) the base resistance property of the fluoroelastomer is reduced.

          The fluoroelastomers of this invention are generally prepared by free radical emulsion or suspension polymerization. Preferably, the polymerizations are carried out in continuous, batch, or semi-batch  
20   emulsion processes well known in the art. The resulting fluoroelastomer latexes are usually coagulated by addition of electrolytes. The precipitated polymer is washed with water and then dried, for example in an air oven, to produce a substantially dry fluoroelastomer gum.

          In a semi-batch emulsion polymerization process, a gaseous  
25   monomer mixture of a desired composition (initial monomer charge) is introduced into a reactor which contains an aqueous solution. Generally, the pH of the aqueous solution is controlled to between 1 and 8 (preferably 3-7), depending upon the type of fluoroelastomer being made. In addition, the initial aqueous solution may contain a nucleating agent, such as a  
30   fluoroelastomer seed polymer prepared previously, in order to promote fluoroelastomer latex particle formation and thus speed up the polymerization process.

The initial monomer charge contains a quantity of TFE, E, perfluoro ether and cure site monomer. The amount of monomer mixture contained in the initial charge is set so as to result in a reactor pressure between 0.5 and 10 MPa.

The monomer mixture is dispersed in the aqueous medium and, optionally, a chain transfer agent may also be added at this point while the reaction mixture is agitated, typically by mechanical stirring.

The temperature of the semi-batch reaction mixture is maintained in the range of 25°C – 130°C, preferably 50°C – 100°C. Polymerization begins when the initiator either thermally decomposes or reacts with reducing agent and the resulting radicals react with dispersed monomer.

Additional quantities of the gaseous major monomers and cure site monomer (incremental feed) are added at a controlled rate throughout the polymerization in order to maintain a constant reactor pressure at a controlled temperature. The polymerization pressure is controlled in the range of 0.5 to 10 MPa, preferably 1 to 6.2 MPa.

Polymerization times in the range of from 2 to 30 hours are typically employed in this semi-batch polymerization process.

A suitable continuous emulsion polymerization process differs from the semi-batch process in the following manner. In the continuous process, gaseous monomers and solutions of other ingredients such as water-soluble monomers, chain transfer agents, buffer, bases, polymerization initiator, surfactant, etc., are fed to the reactor in separate streams at a constant rate. The temperature of the continuous process reaction mixture is maintained in the range of 25°C – 130°C, preferably 80°C – 120°C.

Curable compositions of this invention contain the fluoroelastomer of this invention, a polyhydroxy curative, an acid acceptor and a vulcanization (or curing) accelerator. In the case of fluoroelastomers which contain bromine or iodine atom cure sites, the curable compositions of this invention may, optionally, also contain an organic peroxide and a

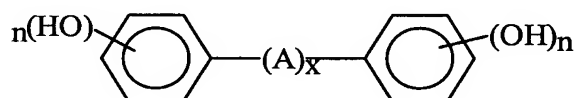


multifunctional curing coagent. Cured articles resulting from the latter compositions contain crosslinks due to both the polyhydroxy and peroxide curing systems and are sometimes referred to in the art as dual cured

5 elastomers.

The curable compositions of the invention contain between 0.1 to 20 parts by weight (preferably 1-3 parts) of polyhydroxy crosslinking agent per 100 parts fluoroelastomer. Typical polyhydroxy cross-linking agents include di-, tri-, and tetrahydroxybenzenes, naphthalenes, and

10 anthracenes, and bisphenols of the formula



where A is a difunctional aliphatic, cycloaliphatic, or aromatic radical of 1-

15 13 carbon atoms, or a thio, oxy, carbonyl, sulfinyl, or sulfonyl radical; A may optionally be substituted with at least one chlorine or fluorine atom; x is 0 or 1; n is 1 or 2; and any aromatic ring of the polyhydroxylic

compound may optionally be substituted with at least one chlorine or fluorine atom, an amino group, a -CHO group, or a carboxyl or acyl

20 radical. Phenolate salts are also active crosslinking agents, such as the dipotassium salt of bisphenol AF. Preferred polyhydroxy compounds

include hexafluoroisopropylidene-bis(4-hydroxy-benzene) (i.e. bisphenol AF); 4,4'-isopropylidene diphenol (i.e. bisphenol A); 4,4'-

dihydroxydiphenyl sulfone; and diaminobisphenol AF. Referring to the

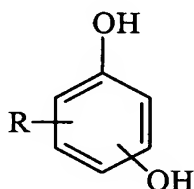
25 bisphenol formula shown above, when A is alkylene, it can be for example methylene, ethylene, chloroethylene, fluoroethylene, difluoroethylene,

propylidene, isopropylidene, tributylidene, heptachlorobutylidene, heptafluorobutylidene, pentyldiene, hexylidene, and 1,1-cyclohexylidene. When

30 A is a cycloalkylene radical, it can be for example 1,4-cyclohexylene, 2-chloro-1,4-cyclohexylene, cyclopentylene, or 2-fluoro-1,4-cyclohexylene.

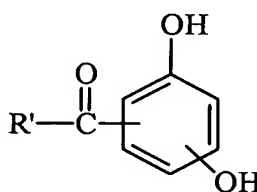
Further, A can be an arylene radical such as m-phenylene, p-phenylene,

o-phenylene, methyl-phenylene, dimethylphenylene, 1,4-naphthylene, 3-fluoro-1,4-naphthylene, and 2,6-naphthylene. Polyhydroxyphenols of the formula



5

or



where R is H or an alkyl group having 1-4 carbon atoms or an aryl group containing 6-10 carbon atoms and R' is an alkyl group containing 1-4  
 10 carbon atoms also act as effective crosslinking agents. Examples of such compounds include hydroquinone, catechol, resorcinol, 2-methylresorcinol, 5-methyl-resorcinol, 2-methylhydroquinone, 2,5-dimethylhydroquinone, 2-t-butyl-hydroquinone; and such compounds as 1,5-dihydroxynaphthalene and 2,6-dihydroxynaphthalene.

15 Additional polyhydroxy curing agents include alkali metal salts of bisphenol anions, quaternary ammonium salts of bisphenol anions, tertiary sulfonium salts of bisphenol anions and quaternary phosphonium salts of bisphenol anions. For example, the salts of bisphenol A and bisphenol AF. Specific examples include the disodium salt of bisphenol AF, the  
 20 dipotassium salt of bisphenol AF, the monosodium monopotassium salt of bisphenol AF and the benzyltriphenylphosphonium salt of bisphenol AF.

Quaternary ammonium and phosphonium salts of bisphenol anions and their preparation are discussed in U.S. Patents 4,957,975 and 5,648,429. Bisphenol AF salts (1:1 molar ratio) with quaternary  
 25 ammonium ions of the formula  $R_1R_2R_3R_4N^+$ , wherein  $R_1$ - $R_4$  are  $C_1$ - $C_8$  alkyl

groups and at least three of  $R_1$ - $R_4$  are  $C_3$  or  $C_4$  alkyl groups are preferred. Specific examples of these preferred compositions include the 1:1 molar ratio salts of tetrapropyl ammonium-, methyltributylammonium- and

5    tetrabutylammonium bisphenol AF. Such salts may be made by a variety of methods. For instance a methanolic solution of bisphenol AF may be mixed with a methanolic solution of a quaternary ammonium salt, the pH is then raised with sodium methoxide, causing an inorganic sodium salt to precipitate. Alternatively, a methanolic solution of bisphenol AF may first

10   be neutralized with a molar equivalent of base (such as sodium methoxide). The quaternary ammonium salt is then added and an inorganic salt precipitates. After filtration, the tetraalkylammonium/BPAF salt may be isolated from solution by evaporation of the methanol. In another method for preparing the curative/accelerator salt, a methanolic

15   solution of tetraalkylammonium hydroxide may be employed in place of the solution of quaternary ammonium salt, thus eliminating the precipitation of an inorganic salt and the need for its removal prior to evaporation of the methanol.

In addition, derivatized polyhydroxy compounds, such as mono- or

20   diesters and trimethylsilyl ethers, are useful crosslinking agents. Examples of such compositions include diesters of phenols, such as the diacetate of bisphenol AF, the diacetate of sulfonyl diphenol, and the diacetate of hydroquinone.

The curable compositions of the invention also contain between 1

25   to 30 parts by weight (preferably 1 to 15 parts) of an acid acceptor per 100 parts fluoroelastomer. The acid acceptor is typically a strong organic base such as Proton Sponge® (available from Aldrich) or an oxirane, or an inorganic base such as a metal oxide, metal hydroxide, or a mixture of 2 or more of the latter. Metal oxides or hydroxides which are useful acid

30   acceptors include calcium hydroxide, magnesium oxide, lead oxide, and calcium oxide. Calcium hydroxide and magnesium oxide are preferred.

Vulcanization accelerators which may be used in the curable compositions of the invention include tertiary sulfonium salts such as  $[(C_6H_5)_2S^+(C_6H_{13})][Cl]^-$ , and  $[(C_6H_{13})_2S(C_6H_5)]^+[CH_3CO_2]^-$  and quaternary ammonium, phosphonium, arsonium, and stibonium salts of the formula  $R_5R_6R_7R_8Y^+ X^-$ , where Y is phosphorous, nitrogen, arsenic, or antimony;  $R_5$ ,  $R_6$ ,  $R_7$ , and  $R_8$  are individually  $C_1$ - $C_{20}$  alkyl, aryl, aralkyl, alkenyl, alkoxy and the chlorine, fluorine, bromine, cyano, -OR, and -COOR substituted analogs thereof, with R being  $C_1$ - $C_{20}$  alkyl, aryl, aralkyl, alkenyl, and where X is halide, hydroxide, sulfate, sulfite, carbonate, pentachlorothiophenolate, tetrafluoroborate, hexafluorosilicate, hexafluorophosphate, dimethyl phosphate, and  $C_1$ - $C_{20}$  alkyl, aryl, aralkyl, and alkenyl carboxylates and dicarboxylates. Particularly preferred are benzyltri-phenylphosphonium chloride, benzyltriphenylphosphonium bromide, tetrabutylammonium hydrogen sulfate, tetrabutylammonium hydroxide, tetrapropylammonium hydroxide, tetrabutylammonium bromide, tributylallylphosphonium chloride, tributyl-2-methoxypropylphosphonium chloride, 1,8-diazabicyclo[5.4.0]undec-7-ene, and benzyldiphenyl(dimethylamino) phosphonium chloride. Other useful accelerators include methyltrioctylammonium chloride, methyltributylammonium chloride, tetrapropylammonium chloride, benzyltrioctylphosphonium bromide, benzyltrioctylphosphonium chloride, methyltrioctylphosphonium acetate, tetraoctylphosphonium bromide, methyltriphenylarsonium tetrafluoroborate, tetraphenylstibonium bromide, 4-chlorobenzyltriphenyl phosphonium chloride, 8-benzyl-1,8-diazabicyclo(5.4.0)-7-undecenonium chloride, diphenylmethyltriphenylphosphonium chloride, allyltriphenyl-phosphonium chloride, tetrabutylphosphonium bromide, m-trifluoromethyl-benzyltrioctylphosphonium chloride, and other quaternary compounds disclosed in U.S. Patent Nos. 5,591,804; 4,912,171; 4,882,390; 4,259,463; 4,250,278 and 3,876,654. The amount of accelerator used is between 0.1

and 20 parts by weight per hundred parts fluoroelastomer. Preferably, 0.5-3.0 parts accelerator per hundred parts fluoroelastomer is used.

Optionally, the curable compositions of the invention may contain a  
5 second curing agent in the form of a combination of an organic peroxide  
and a multifunctional (i.e. polyunsaturated) coagent compound. Examples  
of organic peroxides which are particularly effective curing agents for  
fluoroelastomers include dialkyl peroxides or bis(dialkyl peroxides) which  
decompose at a temperature above 50°C. In many cases one will prefer  
10 to use a di-t-butylperoxide having a tertiary carbon atom attached to a  
peroxy oxygen. Among the most useful are 2,5-dimethyl-2,5-di(t-butylperoxy)hexyne-3 and 2,5-dimethyl-2,5-di(t-butyl-peroxy)hexane.  
Other peroxides can be selected from such compounds as dicumyl  
peroxide, dibenzoyl peroxide, t-butyl perbenzoate, and di[1,3-dimethyl-3-(t-  
15 butyl-peroxy)butyl]carbonate. Multifunctional coagents which cooperate  
with such peroxides to provide curing systems include methacrylates, allyl  
compounds, divinyl compounds, and polybutadienes. Specific examples  
of coagents include one or more of the following compounds: triallyl  
cyanurate; triallyl isocyanurate; tris(diallylamine-s-triazine); triallyl  
20 phosphite; hexaallyl phosphoramidate, N,N-diallyl acrylamide; N,N,N',N'-  
tetraallyl terephthalamide; N,N,N',N'-tetraallyl malonamide; trivinyl  
isocyanurate; 2,4,6-trivinylmethyltrisiloxane; and tri(5-norbornene-2-  
methylene)cyanurate. If a peroxide cure system is present in the  
compounds of the invention, the organic peroxide is generally at a level  
25 between 0.2 to 7 parts by weight (preferably 1 to 3 parts) per 100 parts  
fluoroelastomer and the coagent is present at a level of 0.1 to 10  
(preferably 2 to 5) parts by weight per 100 parts fluoroelastomer.

The curable composition of the invention may contain other  
additives, commonly used in elastomer compounding and processing.  
30 The latter may be introduced into the composition before addition of the  
curative, simultaneously with it, or following the addition. Typical additives  
include fillers, plasticizers, processing aids, antioxidants, pigments, and

the like. The amount of such ingredients which is added will depend on the particular end use applications for which the cured compositions are adapted. Fillers, such as carbon black, clays, barium sulfate, calcium carbonate, magnesium silicate, and fluoropolymers are generally added in amounts of from 5-100 parts by weight per 100 parts fluoroelastomer. The amount of plasticizer used is generally from 0.5-5.0 parts by weight per 100 parts fluoroelastomer. Typical plasticizers include esters, such as dioctyl phthalate and dibutyl sebacate. Processing aids are generally used in amounts of from 0.1-2.0 parts by weight per 100 parts fluoroelastomer. Suitable processing aids include octadecylamine, tetramethylene sulfone, p-chlorophenyl sulfone, and waxes, for example, carnauba wax, that aid in the processing of the compositions.

The fluoroelastomer, polyhydroxy curative, acid acceptor, accelerator and any other ingredients are generally incorporated into the curable compositions of the invention by means of an internal mixer or rubber mill. The resulting composition may then be shaped (e.g. molded or extruded) and cured. Curing typically takes place at about 150°-200°C for 1 to 60 minutes. Conventional rubber curing presses, molds, extruders, and the like provided with suitable heating and curing means can be used. Also, for maximum heat resistance and dimensional stability, it is preferred to carry out a post curing operation wherein the molded or extruded article is heated in an oven or the like for an additional period of about 1-48 hours, typically at from about 180°-275°C, generally in an air atmosphere.

The polymers of the invention and curable compositions of the invention result in cured fluoroelastomer articles which have unusually good base resistance, tensile properties and compression set resistance. Such articles find application as gaskets, seals and tubing, particularly in automotive end uses.

The invention is now illustrated by the following embodiments in which all parts are by weight unless otherwise indicated.

**EXAMPLES****Test Methods**

5                                      Physical properties of the compositions described in the examples were measured according to the following test procedures.

	Mooney Scorch	ASTM D1646
	Oscillating Disc Rheometer (ODR)	ASTM D2084
	Moving Disc Rheometer (MDR)	ASTM D5289
10	Tensile Strength ( $T_B$ )	ASTM D412
	Modulus ( $M_{100}$ )	ASTM D412
	Elongation at Break ( $E_B$ )	ASTM D412
	Hardness	ASTM D2240
	Compression Set-B	ASTM D395

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**Example 1**

A polymer of the invention (Polymer 1) was prepared by a continuous emulsion polymerization process, carried out at 110°C in a well-stirred 4.0-liter stainless steel liquid full reaction vessel. An aqueous solution, consisting of 2.7 g/hour (g/h) ammonium persulfate, 22.2 g/h sodium phosphate dibasic heptahydrate, and 22.2 g/h of ammonium perfluorooctanoate, was fed to the reactor at a rate of 2 L/hour. The reactor was maintained at a liquid-full level at a pressure of 6.2 MPa by means of a backpressure control valve in the effluent line. After 30 minutes, polymerization was initiated by introduction of a gaseous monomer mixture consisting of 6.1 wt.% ethylene (E), 36.9 wt.% tetrafluoroethylene (TFE), 51.3 wt.% perfluoro(methyl vinyl ether) (PMVE) and 5.8 wt.% 1,1,3,3,3-pentafluoropropylene (2H-PFP) fed through a diaphragm compressor. After 2.0 hours, collection of effluent dispersion was begun and lasted for 6 hours. The effluent polymer dispersion, which had a pH of 4.4 and contained 26 wt.% solids, was separated from residual monomers in a degassing vessel at atmospheric pressure. The resulting fluoroelastomer latex was coagulated by addition of an aqueous calcium nitrate solution, filtered and then the fluoroelastomer was washed with deionized water. The wet crumb was dried in an air oven at

approximately 50°-65°C to a moisture content of less than 1 wt.%. About 4 kg of polymer was recovered at an overall conversion of 77.6%. The product, composed of 7.8 wt.% ethylene, 44.2 wt.% TFE, 47.0 wt.% PMVE and 1.0 wt.% 2H-PFP units, was an amorphous fluoroelastomer having a glass transition temperature of – 10°C, as determined by differential scanning calorimetry (heating mode, 10°C/minute, inflection point of transition). Mooney viscosity, ML-10 (121°C), was 50.

#### 10 Example 2

A polymer of the invention (Polymer 2) was prepared by a semi-batch emulsion polymerization process, carried out at 80°C in a well-stirred reaction vessel. A 33-liter, horizontally agitated reactor was charged with 20 liters of deionized, deoxygenated water, 200 g of ammonium perfluorooctanoate and 100 g of sodium phosphate dibasic heptahydrate. The reactor was heated to 80°C and then pressurized to 2.07 MPa with a mixture of 14.5 wt.% TFE, 85.3 wt.% PMVE and 0.2 wt.% 3,3,3-trifluoropropene-1 (TFP). A 35 ml sample of a 10 wt.% ammonium persulfate initiator aqueous solution was then added. A mixture of 7.7 wt.% ethylene, 42.3 wt.% TFE, 47.0 wt.% PMVE and 3.0 wt.% TFP was supplied to the reactor to maintain a pressure of 2.07 MPa throughout the polymerization. The initiator solution was fed continuously at 15 ml/hour through the end of the reaction period. After a total of 8000 g monomer mixture was supplied to the reactor, monomer addition was discontinued and the reactor was purged of residual monomer. The total reaction time was 12 hours. The resulting fluoroelastomer latex was coagulated by addition of an aqueous calcium nitrate solution, filtered and the fluoroelastomer was washed with deionized water. The polymer crumb was dried for two days at 60°C. The product, composed of 7.7 wt.% ethylene, 42.3 wt.% TFE, 47.0 wt.% PMVE and 3.0 wt.% TFP, was an amorphous fluoroelastomer having a glass transition temperature of – 10°C, as determined by differential scanning calorimetry (heating mode,



10°C/minute, inflection point of transition). Mooney viscosity, ML-10 (121°C), was 99.

5    Example 3

          A polymer of the invention (Polymer 3) was prepared by a continuous emulsion polymerization process, carried out at 90°C in a well-stirred 4.0-liter stainless steel liquid full reaction vessel. An aqueous solution, consisting of 1.94 g/hour (g/h) ammonium persulfate, 16.0 g/h sodium phosphate dibasic heptahydrate, and 7.0 g/h of ammonium perfluorooctanoate, was fed to the reactor at a rate of 1.2 L/hour. The reactor was maintained at a liquid-full level at a pressure of 6.2 MPa by means of a backpressure control valve in the effluent line. After 60 minutes, polymerization was initiated by introduction of a gaseous monomer mixture consisting of 6.3 wt.% ethylene, 36.6 wt.% TFE, 55.9 wt.% PMVE and 1.2 wt.% TFP fed through a diaphragm compressor. After 4.0 hours, collection of effluent dispersion was begun and continued for 20 hours. The effluent polymer dispersion, which had a pH of 6 and contained 26 wt.% solids, was separated from residual monomers in a degassing vessel at atmospheric pressure. The resulting fluoroelastomer latex was coagulated by addition of calcium nitrate aqueous solution, filtered and washed with deionized water. The wet crumb was dried in an air oven at approximately 50°-65°C to a moisture content of less than 1 wt.%. About 8 kg of polymer was recovered at an overall conversion of 77%. The product, composed of 8.4 wt.% ethylene, 43.2 wt.% TFE, 46.6 wt.% PMVE and 1.8 wt.% TFP units, was an amorphous fluoroelastomer having a glass transition temperature of – 9°C, as determined by differential scanning calorimetry (heating mode, 10°C/minute, inflection point of transition). Mooney viscosity, ML-10 (121°C), was 76.

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Control A

A control polymer (Control Polymer A) of the prior art was made by substantially according to the process used to prepare Polymer 1 in Example 1, except that the monomer mixture was comprised of 6 wt.% ethylene, 38 wt.% TFE, 55 wt.% PMVE and 1 wt.% 4-bromo-3,3,4,4-tetrafluorobutene-1 (BTFB). The resulting fluoroelastomer had a composition of about 8 wt.% E, 44 wt.% PMVE and 47 wt.% TFE and 1 wt.% BTFB with a ML-10 (121°C) of about 50).

Example 4

A curable composition of the invention (Sample 1) was made by mixing Polymer 1 prepared above with a polyhydroxy curative, acid acceptor, vulcanization accelerator and other ingredients on a conventional two-roll rubber mill, using standard mixing techniques employed in the elastomer industry. A comparative curable composition (Comparative Sample A) was made by a similar procedure except that i) a fluoroelastomer of the prior art was employed (Control Polymer A prepared above), which contained BTFB cure site monomer rather than a cure site monomer used in the fluoroelastomers of this invention, and ii) the comparative composition was crosslinked with a peroxide curing system. The formulations are shown in Table I.

Curing characteristics, tensile properties and compression set resistance were measured according to the Test Methods. ODR measurements were of slabs at 177°C – 3° arc, 24 minute motor. Tensiles and compression set were measured on slabs which had been press cured for 10 minutes at 177°C, followed by a postcure of 24 hours at 200°C in air. The results are also shown in Table I. Cured slabs resulting from the bisphenol curable composition of the invention (Sample 1) had much better compression set than slabs resulting from the peroxide curable composition of the prior art (Comparative Sample A).

**TABLE I**

<b><u>Ingredient, phr<sup>1</sup></u></b>	<b><u>Comp. Sample A</u></b>	<b><u>Sample 1</u></b>
Control Polymer A	100	0
Polymer 1	0	100
Diak 7 <sup>2</sup>	2.25	0
Luperco® 101XL <sup>3</sup>	2.25	0
TBAHS <sup>4</sup>	0	2.5
Bisphenol AF	0	2.5
Zinc Oxide	6	0
Magnesium Oxide	0	3
Calcium Hydroxide	0	6
MT Carbon Black	30	30
<b><u>Curing Characteristics</u></b>		
M <sub>L</sub> , dN·m	27.1	22.3
M <sub>H</sub> , dN·m	74.2	108
t <sub>s2</sub> , minutes	1.2	1.4
t <sub>c90</sub> , minutes	9.5	8.5
<b><u>Tensile Properties</u></b>		
M <sub>100</sub> , MPa	5.0	4.3
T <sub>B</sub> , MPa	9.7	6.9
E <sub>B</sub> , %	235	230
Hardness, Shore A	74	76
<b><u>Compression Set</u></b>		
@150°C, 70 hours, %	57	23
@200°C, 70 hours, %	63	39

<sup>1</sup> phr is parts by weight per 100 parts by weight rubber (i.e. elastomer)

<sup>2</sup> triallyl isocyanurate available from DuPont Dow Elastomers

5 <sup>3</sup> 45% 2,5-dimethyl-2,5-di(t-butyl peroxy) hexane and 55% inert filler available from ATOFINA

<sup>4</sup> tetrabutylammonium hydrogen sulfate

**Example 5**

A curable composition of the invention (Sample 2) was made by mixing Polymer 3 prepared above with a polyhydroxy curative, acid acceptor, vulcanization accelerator and other ingredients on a conventional two-roll rubber mill, using standard mixing techniques employed in the elastomer industry. A comparative curable composition (Comparative Sample B) was made by the same procedure except that a fluoroelastomer of the prior art was employed (Control Polymer A prepared above), which contained BTFB cure site monomer. The formulations are shown in Table II.

Curing characteristics (MDR at 200°C, 24 minutes) were measured according to the Test Methods. The results are also shown in Table II. Sample 2 (a composition of the invention) cured faster than Comparative Sample B (tc90 of 4.32 min. vs. 16.7 min.) and reached a higher state of cure ( $M_H-M_L$  of 9.07 vs. 1.74).

**TABLE II**

<b><u>Ingredient, phr<sup>1</sup></u></b>	<b><u>Comp. Sample B</u></b>	<b><u>Sample 2</u></b>
Control Polymer A	100	0
Polymer 3	0	100
TBAHS <sup>2</sup>	1.96	1.96
Bisphenol AF	1.5	1.5
Maglite D <sup>3</sup>	5.0	5.0
Calcium Hydroxide	3.0	3.0
<b><u>Curing Characteristics</u></b>		
$M_L$ , dN·m	0.70	0.75
$M_H$ , dN·m	2.44	9.82
tc50, minutes	6.0	2.4
tc90, minutes	16.7	4.3

<sup>1</sup> phr is parts by weight per 100 parts by weight rubber (i.e. elastomer)

<sup>2</sup> tetrabutylammonium hydrogen sulfate

20 <sup>3</sup> magnesium oxide available from C.P. Hall

Example 6

5 A curable composition of the invention (Sample 3) was made by  
mixing Polymer 2 prepared above with a polyhydroxy curative, acid  
acceptor, vulcanization accelerator and other ingredients on a  
conventional two-roll rubber mill, using standard mixing techniques  
employed in the elastomer industry. A comparative curable composition  
(Comparative Sample B) was made by a similar procedure except that i) a  
10 fluoroelastomer of the prior art was employed (Control Polymer A  
prepared above), which contained 4-bromo-3,3,4,4-tetrafluorobutene-1  
(BTFB) cure site monomer rather than a cure site monomer used in the  
fluoroelastomers of this invention, and ii) the comparative composition was  
crosslinked with a peroxide curing system. The formulations are shown in  
15 Table III.

Curing characteristics, tensile properties and compression  
set resistance were measured according to the Test Methods. ODR  
measurements were of slabs at 177°C – 3° arc, 24 minute motor. Tensiles  
and compression set were measured on slabs which had been process  
20 cured for 10 minutes at 177°C, followed by a postcure of 24 hours at  
232°C in air. The results are also shown in Table III. Cured slabs  
resulting from the bisphenol curable composition of the invention (Sample  
1) had much better compression set than slabs resulting from the peroxide  
curable composition of the prior art (Comparative Sample A).

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**TABLE III**

<b><u>Ingredient, phr<sup>1</sup></u></b>	<b><u>Comp. Sample B</u></b>	<b><u>Sample 3</u></b>
Control Polymer A	100	0
Polymer 2	0	100
Diak 7 <sup>2</sup>	2.50	0
Luperco® 101XL <sup>3</sup>	2.50	0
Bisphenol AF Salt <sup>4</sup>	0	3.15
Zinc Oxide	6	0
Magnesium Oxide	0	3
Calcium Hydroxide	0	6
MT Carbon Black	30	30
<b><u>Curing Characteristics</u></b>		
M <sub>L</sub> , dN·m	26.2	47.1
M <sub>H</sub> , dN·m	76.7	128.8
t <sub>s2</sub> , minutes	1.3	0.8
tc90, minutes	9.7	3.1
<b><u>Tensile Properties</u></b>		
M <sub>100</sub> , MPa	5.6	9.0
T <sub>B</sub> , MPa	15	13
E <sub>B</sub> , %	275	165
Hardness, Shore A	73	77
<b><u>Compression Set</u></b>		
@150°C, 70 hours, %	48	34
@200°C, 70 hours, %	53	47

<sup>1</sup> phr is parts by weight per 100 parts by weight rubber (i.e. elastomer)

<sup>2</sup> triallyl isocyanurate available from DuPont Dow Elastomers

5 <sup>3</sup> 45% 2,5-dimethyl-2,5-di(t-butyl peroxy) hexane and 55% inert filler available from ATOFINA

<sup>4</sup> methyltributylammonium BPAF salt 1:1 molar ratio